Clean Air and Power Games

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Summary

Can pollution control increase the market power of electricity producers? What are the interactions between pollution control and electricity markets? These questions are important for the design of an efficient electricity market. We investigate the ability of the largest producer in an electricity market to manipulate both the electricity and emission allowances markets to its advantage. We construct a computational model of the Pennsylvania - New Jersey - Maryland electricity market and show that the leader can gain substantial profits by withholding allowances and driving up emission allowance costs for rival producers.

Market power is defined as the ability of players in a market – producers and consumers, for example – to unilaterally or collectively maintain prices above the competitive level. The exercise of market power can result in price distortions, production inefficiencies, and a redistribution of income among consumers and producers. The electricity market is especially vulnerable to the exercise of market power by the producers for three reasons. First, short-term demands for electricity are very inelastic, largely because consumers are shielded from fluctuations in real-time prices. Second, network limitations lead to market separation if transmission lines are congested. Third, supply curves steepen when output is near capacity, implying that the marginal cost increases drastically in segments where the electricity price is determined during peak periods.

Pollution control regulation can significantly increase production costs in electricity markets. The NOx allowances program in the eastern United States, for example, is a cap-and-trade program administered by the U.S. Environmental Protection Agency (USEPA). The amount of NOx released into the atmosphere under this program is controlled by distributing allowances to the producers that must be redeemed to cover actual emissions. These allowances can be traded in a secondary market or banked for future use.

Market power can interfere with the efficiency of the emission control program, yielding higher costs for both emission control and commodity production. An example of such market power is the ability of producers to use allowances as a vehicle to affect the costs of rivals. The consequences of exercising market power can be complicated because of the interaction between the electricity and allowances markets. Empirical analysis of the 2000–2001 California power crisis, for example, suggests that in addition to demand growth, a shortage of hydropower, and excessive reliance on spot markets, some price increases were caused by a large

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producer that intentionally consumed more allowances than necessary, raising the costs for rival producers that were short of allowances.

We construct a Stackelberg game for the Pennsylvania - New Jersey - Maryland Interconnection (PJM) electricity market. This model differs from other oligopolistic models in the following ways. First, interaction between the emissions and electricity markets is explicitly represented in the model. In particular, the allowances price is endogenously determined, as opposed to being an exogenous quantity as in other models. Second, the model is developed from the bottom up and is based on detailed engineering data for a power system with 14 nodes, 18 arcs, and 5 periods, shown in Figure 1.

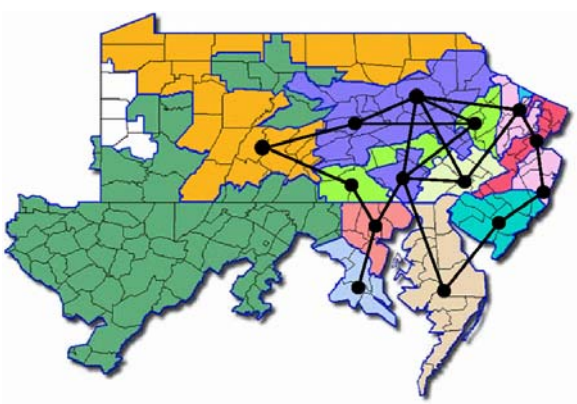

Figure 1: Network topology of PJM market

The data incorporated in the model includes heat rates, emission rates, fuel costs, location, and ownership for each generator. This approach allows for a more realistic estimation of the market power associated with the location of a generator in the network. Moreover, the power flow in the network is represented by a linearized direct-current load flow model in which the Kirchhoff current and voltage laws account for quadratic transmission losses.

The resulting model has 18,500 variables and 9,500 constraints, making it one of the largest Stackelberg games solved to date. A two-phase strategy was used to solve the problem that first finds a feasible iterate by solving a related complementarity problem and then applying an optimization algorithm that builds on recent developments in solving ill-conditioned nonlinear optimization problems.

The solutions to the Stackelberg game for the PJM electricity market show that the leader can gain substantial profits through the exercise of market power at the expense of other producers. Whether the withholding allowances strategy is profitable depends on (among other factors) the net position of the leader in the NOx allowances market. According to this model, some producers may be in a position to profit from withholding allowances; however, it is not optimal for other producers to undertake such practices.

This computational experience is promising for policy modelers interested in investigating the complicated interactions among imperfectly competitive markets.

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